

RESEARCH ARTICLE

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Study Of The Formulation And Durability Of A Low-Permeability Hydraulic Concrete For Quay Piles In Permanent Immersion For Offshore Construction: The Case Study Of Quay Seventeen (17) At The Autonomous Port Of Douala, Littoral Region Of Cameroon.

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ABSTRACT

The durability of offshore structures is a major challenge in the context of port infrastructure development in Cameroon. Quay piles, which are permanently submerged in a marine environment, are particularly exposed to physico-chemical stresses that can impair their performances and reduce their lifetime. To tackle this challenge, this study focuses on the design of a low-permeability hydraulic concrete intended for this type of structures. The objective of this work is to design a durable concrete using local materials whilst limiting the penetration of aggressive agents into the cementitious matrix. The materials used are Sanaga sand 0/5, crushed gravels 5/16 and 16/25 from the Logbadjeck quarry, Dangoté cement CEM II 42.5 R, water and the Sika ViscoCrete - 2025 HE superplasticiser. The Sika ViscoCrete - 2025 HE is used for all concretes where we want great workability with a low water/cement ratio, short term high mechanical strengths, and low porosity. Its dosage varies between 0.3 and 2% by weight of cement and the values 0%, 0.3% and 2% are considered in this work. The aggregates underwent physical and mechanical characterisation through several laboratory tests (gravel cleanliness, sand equivalent, particle size analysis, specific gravity, bulk density and water absorption). The concrete mix design was carried out using the Dreux-Gorisse method, chosen for its suitability for local materials and its ability to optimise concrete compactness. Compressive and tensile strength tests were carried out on hardened concrete. The results obtained showed an average compressive strength increasing from 31,2 MPa for 0% superplasticiser to 32.725 MPa for 2% superplasticiser at 28 days and from 32,5 MPa for 0% superplasticiser to 34.19 MPa for 2% superplasticiser at 35 days. The average water absorption coefficients on the hardened concrete decreased from 2.01 % for 0% superplasticiser to 1.29% for 2% superplasticiser. The study also highlighted the importance of granular compactness and control of the water-to-cement ratio in reducing permeability and improving the durability of concrete in a marine environment or for offshore construction. The results demonstrated that it is possible to produce, using locally available materials in Cameroon, a durable hydraulic concrete suitable for the construction of permanently submerged quay piles.

Keywords: Hydraulic concrete, low permeability, durability, marine environment, quay piles, local materials.

1. INTRODUCTION

1.1. Background to the study

Infrastructure development is a key driver of economic and social growth in developing countries. In Cameroon, this trend forms part of a clear commitment to modernisation through the implementation of major infrastructure projects, particularly in the port, road and energy sectors. Among these infrastructure projects, maritime structures such as quays, jetties and piles play a strategic role in the development of foreign trade and the country's integration into international trade, particularly in port cities such as Douala. Furthermore, in a context where the optimisation of local resources is encouraged, the use of materials available in Cameroon, such as alluvial sand and local crushed aggregates, necessitates an adaptation of concrete mix design methods. It therefore becomes essential to adopt approaches capable of incorporating the specific characteristics of these materials whilst ensuring the required performance in terms of strength and durability.

1.2. Objective

The objective of this work is to formulate a high-performance concrete using local materials, whilst ensuring low permeability and good resistance to the aggressive effects of the marine environment. To achieve this objective: Characterisation of raw materials was carried out; concrete mix design was carried out using Dreux-Gorisse method; Sika ViscoCrete - 2025 HE superplasticiser was used to get great workability of concrete with a low water/cement ratio, short term high mechanical strengths, and low porosity; Compressive and tensile strength tests on hardened

concrete were carried out to assess the performance of the concrete, particularly in terms of mechanical strengths and durability.

2. LITERATURE REVIEW

2.1. History of high-performance concrete

Concrete is a composite material formed by combining control proportion of cement, aggregates, water, and sometimes mineral admixtures and additives in small quantities. This mixture is designed so that, once hardened, it produces a solid product whose mechanical properties surpass those of even the best natural rocks. Concrete is very strong in compression but very weak in tension. It was this weakness that led to the development of reinforced concrete in 1784, enabling this lack of tensile strength to be compensated for (Delhumeau, 1999).

Originally, concrete consisted simply of three components: cement, aggregates and water, according to Auguste Perret, the leading figure in modern concrete architecture. The cement used was mainly Portland cement, obtained by mixing clay and limestone (or other materials rich in lime, silica, alumina and iron oxide), then heating them to a high temperature before grinding them into a fine powder. Subsequently, chemical admixtures were introduced to improve certain properties of concrete, both in the fresh and hardened states. At the same time, inorganic materials were incorporated, mainly for economic reasons, as these materials are often less expensive than Portland cement due to their abundance in nature (Vichot, 2008).

Nowadays, the requirements for concrete are increasingly varied. For example, the Abrams cone slump can range from zero for fast-demoulding concretes to over 25 cm for self-compacting concretes. The compressive strengths required after 28 days can range from moderate values, around 10 MPa for mass concrete, up to very high levels, exceeding 200 MPa for certain specialised precast products (Simonnet, 2005). These advances demonstrate the flexibility of concrete, which can be formulated to meet very specific requirements in the construction sector.

2.2. Components of high-performance concrete

High-performance concrete consists of aggregates, water, cement, admixtures (such as plasticisers and superplasticisers) and, in some cases, mineral additives. It may also include a setting retarder to extend the working time before hardening. It is essential that the superplasticiser and the setting retarder are compatible with each other and with the cement used (Tanaka, 1999). Due to the influence of cement strength on the performance of high-concrete, a Class 42.5R cement is preferred when seeking to achieve higher early strength (Karmazsin, 1978).

2.2.1. Cement

The cement used must comply with the requirements set out in standard JTS 202-2011. A crucial factor in the choice of cement is its compatibility with the superplasticiser. Indeed, the fineness of the cement and its chemical composition can affect the effectiveness of the superplasticiser (Giroud, 2018). It is recommended to avoid slow-setting cements, as high dosages of superplasticiser may prevent demoulding, even after 24 hours (Canovas, 1995). In other words, the mechanical strength of concrete depends largely on the fineness of the clinker grind. A higher fineness increases the proportion of hydrates present in the hardened cement (Regourd, 1982). The specific surface area of the cement, measured using the Blaine method, should ideally be between 3,500 and 4,000 cm²/g. However, an excessively high specific surface area results in a cement rich in fine particles, which can generate significant hydration heat, thereby posing a risk of rapid setting and thermal cracking in the concrete. Furthermore, to achieve good compaction in high performance concrete, it is preferable to limit the size of the cement's fine particles to around 1 µm, in order to avoid harmful granular interactions between ultrafine particles (Larrad, 1988).

As regards the water-to-cement ratio (W/C), a value of 0.35 corresponds approximately to the quantity of water required for complete cement hydration. This means that a significant quantity of cement grains remains unhydrated in high-performance concrete, even after a long period. In addition to its role as a binder, cement also functions as a fine aggregate in the concrete mix design (Regourd, 1982).

2.2.2. Aggregates

Aggregates are fundamental components in the composition of concrete, as they influence both its properties and its cost. They are defined as a collection of mineral particles used in the manufacture of mortars and concrete, as well as in foundation works, road sub-bases, and as ballast for railway tracks. However, there are two main types of aggregates: Natural aggregates, which are derived from loose or massive rock extracted on site and undergo only mechanical processing such as crushing, screening, washing and grading; Artificial aggregates, which result from the thermal processing of rocks, ores, industrial by-products (such as slag and waste), or from the recovery of material from the demolition of concrete structures, often referred to as recycled aggregates.

To ensure the construction of reliable structures that comply with standards and offer optimum technical and economic efficiency, it is essential to have a thorough understanding of the characteristics of aggregates, as these have a significant impact on the dimensional, physicochemical and mechanical properties of concrete (NF EN 12620).

Sand is defined as the fraction of stone aggregates whose grains have a size between 0.16 mm and 5 mm (NF EN 12620), although these limits may vary depending on the classification system used. In other words, it is a material with a maximum grain diameter of 5 mm or less, and in which the proportion of grains passing through a 0.16 mm sieve does not exceed 30 per cent.

2.2.3. Water

The NF EN 1008 standard recommends the use of potable water for mixing concrete. However, it is often difficult to meet this requirement on construction sites, leading to the use of non-potable water. Nevertheless, this water must comply with the specifications of standard JGJ 63-2006 and must not impair the setting or hardening of the cement, nor cause corrosion of the reinforcement.

Mixing water, which is determined by the water-to-cement ratio (W/C), is a crucial element in the formulation of concrete. It fulfils two main functions: It initiates the hydration of the cement, which leads to the setting and hardening of the concrete through the formation of stable hydrated compounds with adhesive properties; It contributes to the workability of fresh concrete, allowing for easy handling during application. This is due to its lubricating effect on the aggregates and the interaction between the fine grains and the water.

It is important to note that, to ensure good workability, a greater quantity of water is required than is strictly necessary for hydration. For example, with a W/C ratio of 0.5, approximately half of the water used will remain in the concrete after the setting and hardening process. This water is distributed throughout the concrete and may lead to the formation of pores and voids. A high number of larger pores weakens the structure of the material and reduces the strength of the concrete (Mehta, 1990).

2.2.4. Admixtures

Admixtures are water-soluble substances added to concrete in concentrations not exceeding 5 per cent by weight of the cement, in order to improve certain properties (NF EN 934-2+A1). They offer concrete producers a wide range of options to facilitate the placement of concrete, adapt it to cold or hot mixing conditions, reduce construction costs, improve the properties of hardened concrete and even impart new characteristics to it.

Among the admixtures that influence the workability of concrete are superplasticisers. These are water-soluble organic polymers, created through a complex polymerisation process that produces long molecular chains. These molecules wrap themselves around the cement particles, causing – depending on their nature – either electrostatic repulsion by neutralising the electrical charges on the surface of the particles, or steric repulsion by pushing the particles away from one another (Guiraud, 2018).

2.2.5. Mineral admixtures

Mineral admixtures generally take the form of fine or ultrafine powders of small particle size. They are incorporated into concrete in quantities of approximately 10 per cent of the cement's weight (NF EN 15167-1). These admixtures can be classified as active or inert and help to improve the consistency of fresh concrete, as well as its performance and durability considering their physicochemical properties (Mbessa, 2004).

Two categories of admixtures can be distinguished: Type I admixtures, which include fillers, limestone and siliceous materials, and Type II admixtures, comprising fly ash, slag and silica fume. These admixtures can be used to partially replace cement according to the principle of equivalent binder, but only with Portland CEM II cements (Dreux, 2007).

2.3. Properties of high-performance concrete

To optimise the use of concrete, it is essential to fully understand its characteristics in both the fresh and hardened states (Baron, 1982).

2.3.1. Properties in the fresh state

The various properties of high-performance concrete (HPC) result from its low porosity:

➤ **Mechanical strengths:** HPC exhibits high compressive strengths from the earliest stages due to a rapid rise in strength, and continues to increase significantly over the long term (beyond 28 days). For example, an HPC with a strength of 60 MPa can reach approximately 15 MPa in just 24 hours and up to 60 MPa in 14 days (Malier, 1992). Furthermore, these concretes exhibit better adhesion between the aggregates and the cement paste, meaning that the strength of the matrix is almost equivalent to that of the aggregates, or even higher. Consequently, under compression, cracks also propagate through the aggregates, thereby increasing the breaking strength (Baron, 1982).

➤ **Impermeability:** Owing to their low porosity, high-performance concretes have very low permeability (Aïtcin, 2001).

- **Resistance to aggressive agents:** The low permeability of HPC provides good protection against the penetration and transfer of aggressive agents in gaseous or liquid form into the concrete (such as seawater, sulphate-containing water, acidic solutions and carbon dioxide) (Simonet, 2005).
- **Shrinkage:** Shrinkage due to drying in the hardened state is less pronounced in high-performance concrete (HPC) because of a lower water-cement ratio (Pedeche, 1994).
- **Fire resistance:** Due to the density of the material, the water vapour generated inside the concrete when the temperature exceeds 100 °C cannot escape rapidly to the outside. Compared with conventional concrete, HPC will lose its strength more rapidly if the temperature exceeds this limit (Nchambou, 1995).

3. MATERIALS AND METHODS

3.1. Location of the Study Area

Figure 1 presents the study area, which is located at the Autonomous Port of Douala, in the Douala I sub division, Wouri division, in the Littoral Region of Cameroon. The site is referenced by geodetic coordinates: latitude North: 4.047250 and longitude East: 9.686050.

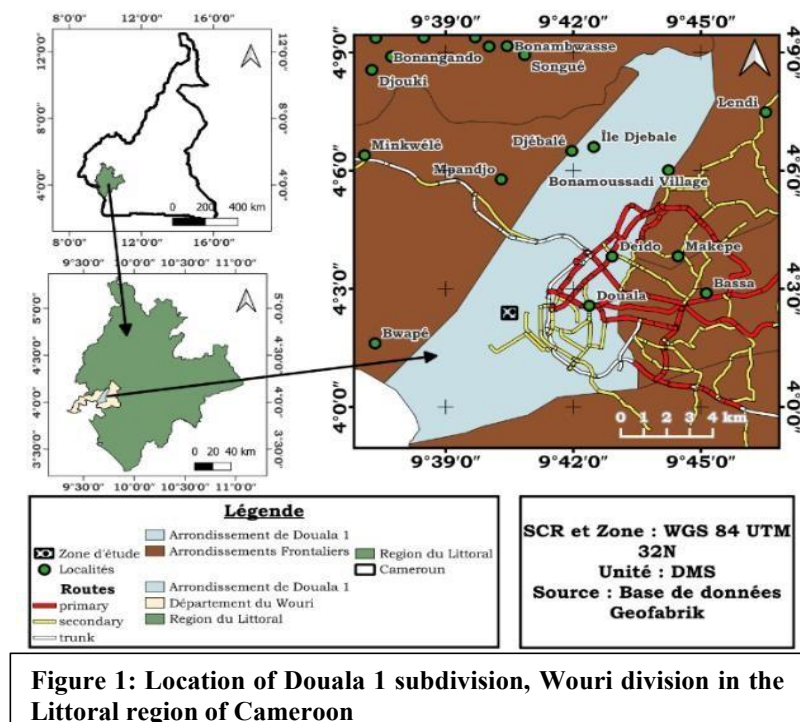


Figure 1: Location of Douala 1 subdivision, Wouri division in the Littoral region of Cameroon

The maritime site is situated to the north of the study area's boundary and corresponds to the location of the future quay.

It is characterised by: a body of water opening onto the River Wouri; depths varying according to the survey points; direct tidal influence; the presence of existing structures; ongoing port activities; and access and traffic constraints (Figure 2).



Figure 2: Map showing the location of the project site and the various sounding points

The site location of the project is also presented on figure 3.

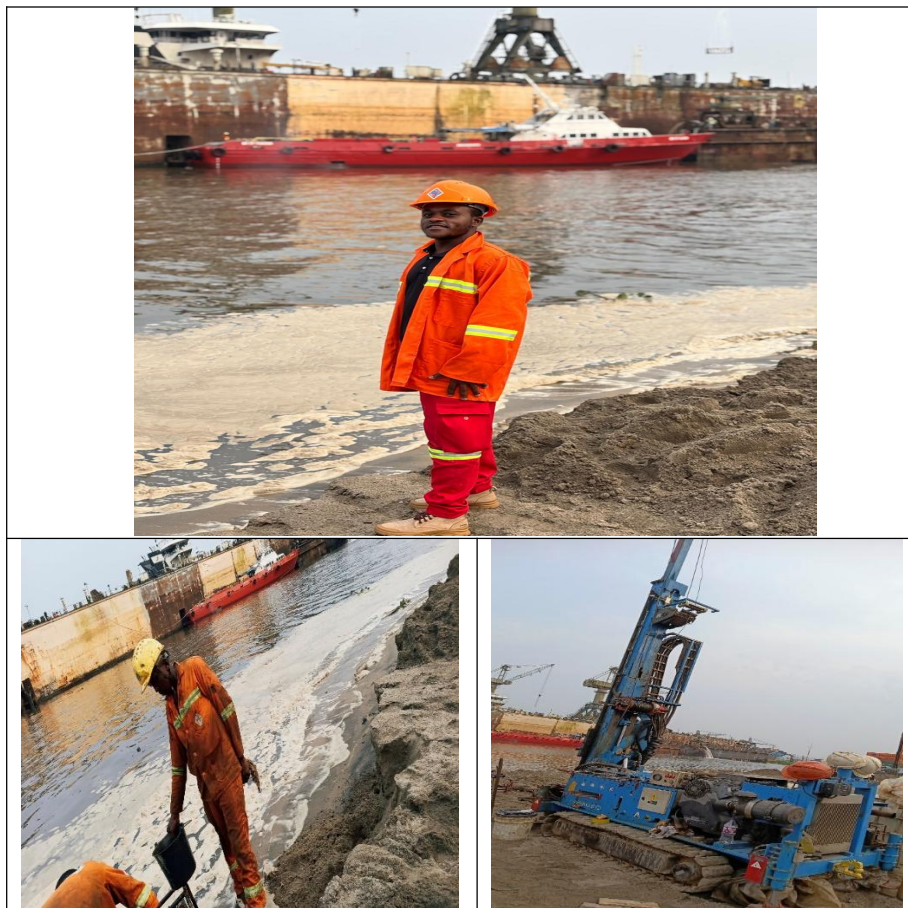


Figure 3: Site location of the project

➤ Topography

Located in the coastal region of south-western Cameroon, on the banks of the Wouri estuary and close to the Atlantic Ocean. The town lies at a low average altitude of approximately 13 to 20 metres above sea level. It has a generally flat and low-lying topography, featuring numerous coastal plains, marshy areas, mangroves and wet valleys, with soils that are often sandy-clay and hydromorphic, and a high density of watercourses and branches of the River Wouri.

➤ Climate

The city of Douala is characterised by high temperatures throughout the year, with an annual average of around 26 to 27 °C (the hottest months being January to March, and the coolest July and August); rainfall is high, averaging 4,000 mm per year, with average monthly figures. The prevailing winds are of an oceanic nature and are not particularly strong. Secondary winds, such as land and sea breezes, are sometimes observed (Figure 4).

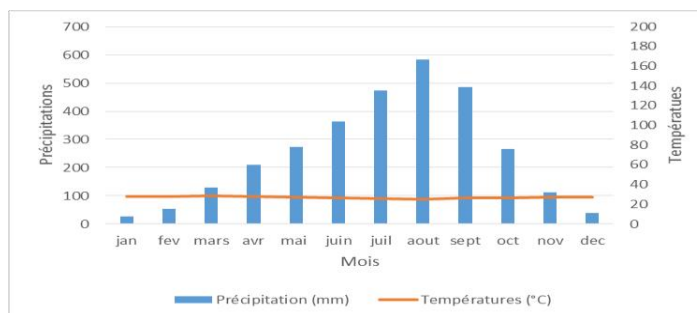


Figure 4: Ombrothermic diagram for Douala (2014–2025)

Source: NASA, 2025

➤ Vegetation

The city of Douala lies within the equatorial dense rainforest zone. The vegetation is strongly influenced by the hot and humid climate, as well as by the abundance of rainfall. It consists mainly of mangroves located along the Wouri estuary and in marshy areas, evergreen tropical rainforests, and hydrophilic vegetation occupying the lowlands. Mangroves make up the bulk of the vegetation in the estuarine areas, whilst coconut palms, other palm trees and secondary species dominate in several urbanised areas.

➤ Geology

Douala forms part of the Douala-Kribi/Campo coastal sedimentary basin. The city's geology is dominated by sedimentary formations consisting mainly of sand, clay, silt and recent alluvial deposits of fluvial-marine origin. The ground conditions generally exhibit high moisture content due to the proximity of the water table and the region's high rainfall. The soils are predominantly loose and poorly consolidated, particularly in marshy areas and low-lying areas (Figure 5).

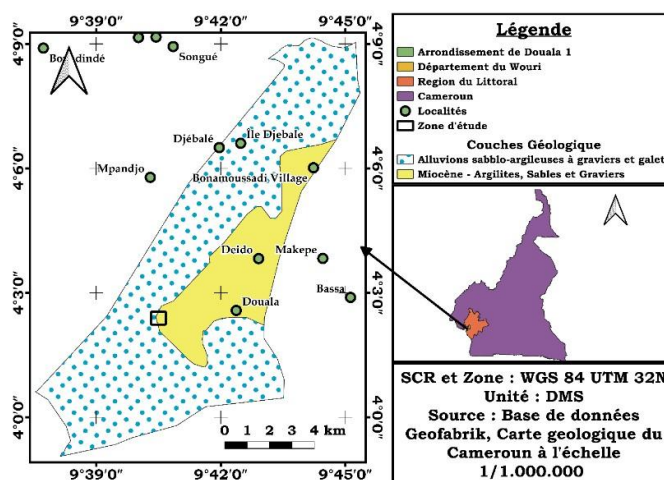


Figure 5: Geological map of Douala

➤ Geomorphology

Located in the Wouri estuary, on the Atlantic coast of Cameroon, the city forms part of Cameroon's coastal sedimentary basin and has a generally flat to gently undulating topography. It lies at a low altitude, generally between 0 and 60 m. The proximity of the Atlantic Ocean and the Wouri estuary system strongly influences the morphology of the terrain.

➤ Hydrography of Douala

The hydrography of Douala is dominated by the River Wouri and its estuary. The hydrographic network also includes several watercourses such as the Dibamba and the Mungo, as well as a network of natural drainage channels and marshy areas. Water flows are strongly influenced by heavy rainfall and tidal effects linked to the proximity of the Atlantic Ocean (Figure 6).

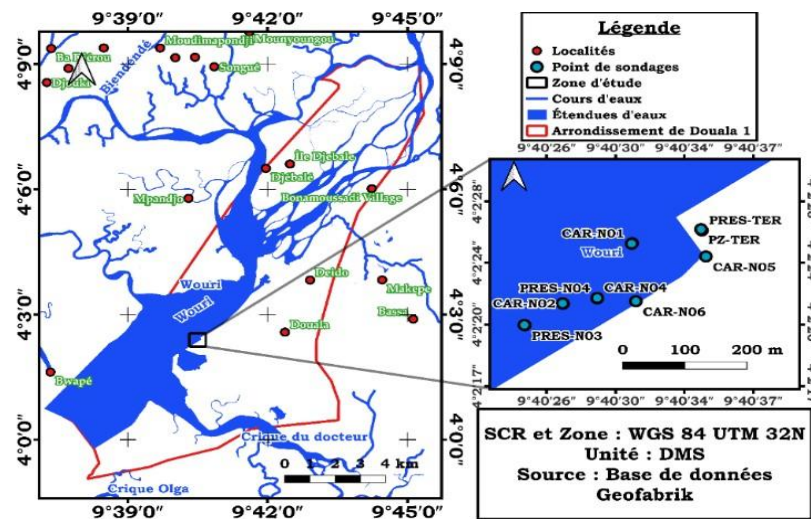


Figure 6: Hydrographic map of Douala

3.2. Materials used

All materials used for the formulation meets the requirements of the ISO 9001 standard, thereby ensuring optimum quality and reliability and have been calibrated by the LABOGENIE.

➤ water

The water used for the project comes from a borehole tapping into an aquifer, drilled at the manufacturing site to a depth of approximately 70 m.

➤ Aggregates

The 5/16 and 16/25 grade gravel used in this project comes from the Logbadjeck quarry, where metamorphic gneiss outcrops. This rock offers exceptional strength, with a compressive strength exceeding 100 MPa, making it ideal for the formulation of high-performance concrete. The sand used comes from the River Sanaga and is rolled one.

➤ Cement

As part of this project, CEM II AM (Q-L) 42.5 R cement, manufactured by CIMPOR for its performance, is being used. This cement is specifically designed for structures requiring immediate demoulding and high short-term strength, in accordance with standard NC 234:2017. CEM II B (Q-L) 42.5 R cement is a Portland cement, characterised by a clinker content of between 80 and 94 per cent, combined with an addition of pozzolan (P) representing between 6 and 20 per cent of the composition.

➤ Admixture

The admixture selected for the formulation of this concrete is a high-performance superplasticiser, known as Sika ViscoCrete - 2025 HE. The Sika ViscoCrete - 2025 HE is used for all concretes where we want great workability with a low water/cement ratio, short term high mechanical strengths, and low porosity. This product offers an impressive water-reduction rate of 30% to 40%, thereby optimising the concrete formulation. The dosage varies between 0.3 to 2% by weight of cement and the maximum value of 2% is considered in this work to produced maximum mechanical strengths and minimum porosity.

3.3. Methods

The formulation is carried out with the Dreux–Gorisse method, as it offers the best balance between accuracy, simplicity and suitability for the context of this study. It allows for the simultaneous consideration of the target strength, workability, water-to-cement ratio, compactness, maximum aggregate size, gradation and the actual characteristics of local materials, whilst remaining simple to apply with the resources available. It is also widely used and taught in French-speaking Africa and is suitable for concrete with strengths ranging from 15 to 40 MPa, corresponding to the strength sought in this study. Conversely, the Bolomey method optimises the particle size distribution but does not directly determine the cement content and requires the parameters to be adjusted to suit local materials. The Faury method offers good compactness, but it is more complex, requires knowledge of the specific surface area of the aggregates, and is less suitable for highly workable concrete. The Baron–Lesage method is the most accurate, but it requires a well-equipped laboratory, several test mixes, high costs and a significant time commitment, which exceeds the scope of our study. The ACI 211.1 method is effective, but its charts were drawn up using North American aggregates and require recalibration for Cameroonian aggregates. Finally, standard mix designs are quick to prepare but do not guarantee the strength, durability or low permeability required. Given the objective of producing low permeability hydraulic concrete for quay piles in permanent immersion in a marine environment, using

sand from the Sanaga, gneiss aggregates and CEM II 42.5 R cement, the Dreux–Gorisse method appears to be the most appropriate.

3.3.1. Tests on aggregates

3.3.1.1. Water content test (NF P 94 – 049-1)

The aim of this test is to determine the quantity of water present in a material by measuring the loss of mass following drying at a specific temperature. The principle involves drying a sample at a temperature of 105 °C for 24 hours until its mass remains constant. The difference in mass before and after drying is used to calculate the moisture content, expressed as a percentage of the dry mass (Equation 1).

$$w = \frac{M_h - M_s}{M_s} \cdot 100 \quad (1)$$

Where:

ω : Water content (%);

Mh: Wet mass (g);

Ms: Dry mass (g).

3.3.1.2. Sand equivalent test (EN 933-8)

The aim of this test is to determine the degree of cleanliness of the sand by taking a sample of sand; placing it in a graduated cylinder containing a flocculating solution; shaking the cylinder to suspend the fine particles; after settling, the sand grains settle at the bottom of the cylinder and the clay and silt particles remain in suspension or form an upper layer. The sand equivalent value is given by Equation 2:

$$ES = \frac{h_s}{h_t} \cdot 100 \quad (2)$$

Where:

ht: total height of the clay suspension (cm);

hs: height of the sand layer (cm).

3.3.1.3. Surface cleanliness

The purpose of the test is to determine the degree of cleanliness of the gravel. To do this, a sample of dry gravel is taken, the 0.5 mm sieve fraction is washed, and the oversize material is retained and placed in an oven (105°C) for 24 hours until a constant dry mass is obtained (Equation 3).

$$P = \frac{P_s}{P_t} \cdot 100 \quad (3)$$

Where:

Ps: mass of dry material after washing (g);

Pt: weight of dry material before washing (g).

3.3.1.6. Specific weight (NF P 94-054 (1991) and NF EN ISO 17892-3)

This method aims to determine the true density (ρ_s) of a material by calculating the ratio of its mass to its volume, excluding pores or voids. The principle involves measuring the volume of a solid sample using Archimedes' principle. First, the dry sample (Ms) is weighed using a precision balance. Next, a container is filled with water to a marked level, and the sample is completely submerged in it to remove any air bubbles. The volume (Vs) of the sample corresponds to the volume of water displaced; this can be measured directly using a graduated cylinder or calculated by weighing the displaced water. The values of specific weight are given by equation 4.

$$\rho_s = \frac{M_s}{V_s} \quad (4)$$

Where:

Ms: mass of the dry material (g);

Vs: volume of solid materials or volume of water displaced (cm³).

3.3.1.7. Water absorption coefficient test of gravel

Its purpose is to determine the amount of water that the gravel can absorb relative to its dry mass. The principle of the test consists of measuring the mass of the gravel in the dry state (Ms), then saturating it with water until it reaches a constant mass (Mc). The absorption values are given by equation 5.

$$A_b = \frac{M_c - M_s}{M_s} \cdot 100 \quad (5)$$

where:

Mc: constant mass after saturation (g);

Ms: dry mass (g).

3.3.1.8. Particle size analysis test by dry sieving (NF EN 933-1 and NF EN 933-2)

This method is used to determine the particle size distribution of a granular material, such as sand and gravel. The principle of the test involves separating the particles of the material according to their size by passing them through a series of stacked sieves, with mesh sizes decreasing in size. Each sieve retains particles larger than its mesh size. After sieving, the mass of material retained on each sieve is weighed. The particle size distribution is expressed as the percentage by mass passing through each sieve (Equation 6).

$$P_i = \frac{M_p}{M_t} \cdot 100 \quad (6)$$

Where:

Pi: percentage of material passing through the sieve (%);
Mp: cumulative mass passing through the sieve (g);
Mt: total mass of the dry sample (g).

In the specific case of sand, its fineness modulus (M_f) is calculated (Equation 7).

$$M_f = \frac{\sum (\text{retained materials on sieves with module 23,26,29,32,35,38})}{100} \quad (7)$$

Where:

M_f : fineness modulus of the sand (%).

3.4. Determination of aggregate masses from Dreux-Gorisse method and admixture mass

Given the total absolute volume of aggregates (V) and the absolute volume percentages of sand (S %), gravel 5/16 (g %) and gravel 16/25 (G %), it is then possible to determine the volumes of sand (Vs), gravel 5/16 (Vg) and gravel 16/25 (VG), as well as their respective masses (S, g and G) and admixture mass (Equation 8).

$$\begin{aligned} V_S &= V \cdot S\% & S &= V \cdot S\% \cdot \rho_S (S) \\ V_g &= V \cdot g\% & g &= V \cdot g\% \cdot \rho_S (g) \\ V_G &= V \cdot G\% & G &= V \cdot G\% \cdot \rho_S (G) \end{aligned} \quad (8)$$

Admixture (A) = from 0.3 to 2% of cement mass (0%, 0.3% and 2%)

Where:

$\rho_s (S)$ Specific gravity of sand;
 $\rho_s (g)$ Specific gravity of gravel 5/16;
 $\rho_s (G)$ Specific gravity of gravel 16/25.

3.5. Compressive strength test on hardened concrete (NF P 18-400, NF EN 12390-1, NF EN 12390-2 and NF EN 12390-3)

The immersion of test samples for 28 days before crushing is presented on figure 7.



Figure 7: Immersion of test samples for 28 days before crushing

The crushing of test samples in the press at 28 days is presented on figure 8.



Figure 8: Crushing of test samples at 28 days

This test determines a concrete's ability to resist compressive forces. It involves applying an increasing compressive load to a cylindrical or cubic specimen of the material until it fails. The compressive strength (R_c) is calculated by dividing the maximum applied load (F_{max}) by the cross-sectional area of the specimen (S) (Equation 9):

$$R_c = \frac{F_{max}}{S} \quad (9)$$

Where:

R_c : compressive strength (MPa);

F_{max} : maximum force (kN);

S : Cross sectional area of a specimen (mm^2).

4: RESULTS AND DISCUSSION

4.1. Water content of the aggregates

The average values of water content of Sanaga sand 0/5, Logbadjeck gravel 5/16 and gravel 16/25 are presented in Table 6.

Table 6: Average water content of Sanaga sand and Logbadjeck gravels

Average water content of Sanaga sand and Logbadjeck gravels					
Aggregates	Samples	Wet mass of aggregates	Dry mass of aggregate	Water content w (%)	Average water content w (%)
Sand 0/5	1	296,49	286,32	3,92	3,84
	2	266,8	258,07	3,76	
	3	269,98	260	3,84	
Gravel 5/16	1	300,66	300,61	1,05	1,275
	2	297,43	298,25	1,43	
	3	299,98	296	1,345	
Gravel 16/25	1	305,89	302,09	1,39	1,24
	2	305,39	302,18	1,16	
	3	302,5	299	1,17	

Table 6 shows that the value of water content for Sanaga Sand is 3.84%, that of Logbadjeck gravel 5/16 is 1.275% and the one of Logbadjeck gravel 16/25 is 1.24%. These values are similar to those obtained by Moundom et al. 2022 for sand and gravels from SAFRICAS in Democratic Republic of Congo.

4.2. Specific gravity of the aggregates

The average specific gravity values (ρ_s) of Sanaga sand 0/5, Logbadjeck gravel 5/16 and gravel 16/25 are presented in Table 7.

Table 7: Average specific values of Sanaga sand and Logbadjeck gravels

Average specific values of Sanaga sand and Logbadjeck gravels					
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Aggregates	Samples	Mass of dry materials Ms (g)	Volume of solid materials Vs (cm ³)	Specific gravity ρ_s (g/cm ³)	Average Specific gravity ρ_s (g/cm ³)
Sand 0/5	1	500.78	185.4	2.702	2.689
	2	500.4	187	2,676	
	3	500,15	186	2,689	
Gravel 5/16	1	367.94	125.3	2,936	2.741
	2	376.26	147.7	2,547	
	3	356,2	130	2,74	
Gravel 16/25	1	180	69.2	2,601	2.63
	2	160	60.2	2.659	
	3	170,95	65	2,63	

Table 7 shows specific densities of 2.689 g/cm³ for Sanaga sand 0/5, 2.741g/cm³ for Logbadjeck gravel 5/16 and 2.63 g/cm³ for Logbadjeck gravel 16/25. These values are similar to those of dense aggregates obtained by Moundom *et al.* 2022 with values of 2.5 g/cm³ for sand and 2.63 g/cm³ for gravel both from SAFRICAS in Democratic Republic of Congo.

4.3. Water absorption capacity of Logbadjeck gravels after 24 hours

Table 8 shows the values of water absorption of the Logbadjeck gravels after 24 hours.

Table 8: Water absorption capacity of Logbadjeck gravels after 24 hours

Water absorption capacity of Logbadjeck gravels after 24 hours					
Materials	Samples	Dry mass (g)	Wet mass (g)	Water absorption (%)	Average water absorption (%)
Gravels	1	1500	1505	0.33	0.30
	2	1500	1504	0.27	

Table 8 shows the average water absorption capacity of Logbadjeck gravels after 24 hours of 0.3 % for Logbadjeck gravels 5/16 and 16/25. These values are similar to those obtained by Moundom *et al.* 2022 for gravel from SAFRICAS in Democratic Republic of Congo. Laboratory tests have revealed that the 5/16 gravel has a water absorption of 0.3 per cent (below the 1 per cent limit for Type I aggregates according to french standard). This result comfortably meets the requirements of the Specification, which stipulates a water absorption of less than 1 per cent. This absorption capacity confirms that this gravel is ideal for the mix design of concrete resistant to chemical attack, ensuring durability and stability in aggressive environments.

4.4. Particle size analysis of aggregates

The values of particle size analysis of sand and gravels studied are presented in figure 9.

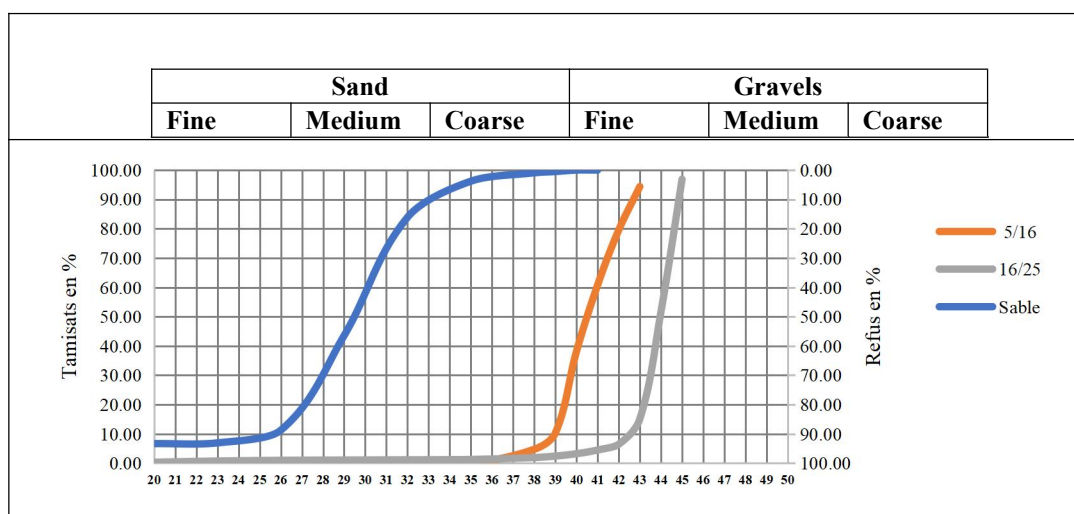


Figure 9: Particle size distribution curve of Sanaga sand 0/5 and Logbadjeck gravels 5/16 and 16/25

The particle size distribution curve of figure 9 shows satisfactory continuity.

4.5. Sand equivalent values

The average sand equivalent values of Sanaga sand 0/5 (visual and with piston) are presented in table 9.

Table 9: Average Sand equivalent values of Sanaga sand 0/5

Average Sand equivalent values of Sanaga sand 0/5						
Sample	Total height H ₀	Visual height	Piston height	SE	Average SE	
SE measured with Piston						
1	9,4		9,3	98,9	98,9	
2	9		8,9	98,9		
SE measured visually						
1	9,4	9,3		98,9	98,9	
2	9	8,9		98,9		
SE is Sand Equivalent						

Table 9 shows the average Sand Equivalent value of Sanaga Sand 0/5 of 98,9%. This value is higher than 80% for piston height and 85% for the visual height, and according to the Dreux classification scale (1981), the sand is very clean. The almost total absence of fine may lead to a plasticity defect in the concrete, which must be corrected by increasing the cement dosage. This value of 98,9% is higher than 85,72% obtained by Moundom *et al.* 2022 for sand 0/4 from SAFRICAS in Democratic Republic of Congo. This provides information on the sand's cleanliness and the possible presence of clay. The test carried out gives us an equivalence of 98.9 per cent, which classifies the sand as first-class according to standard NF P18-598, stipulating excellent sand cleanliness with values exceeding 80 per cent for the piston height and 85 per cent for the visual height. This result will ensure excellent binder-aggregate adhesion, low water consumption, greater mechanical strength and greater durability.

4.6. Surface cleanliness of Logbadjeck gravels 5/16 and 16/25

The surface cleanliness of Logbadjeck gravels 5/16 and 16/25 are presented in table 10.

Table 10: Surface cleanliness of Logbadjeck gravels 5/16 and 16/25

Surface cleanliness of Logbadjeck gravels 5/16 and 16/25				
	Initial dry weight (g)	Dry weight of material passing through the 0.5 sieve (g)	Percentage passing (%)	Average percentage passing (%)
Gravel 5/16				
Sample 1	1621	4	0.25	0.21
Sample 2	1641	3	0.18	
Gravel 16/25				
Sample 1	1141	74	6.49	6.08
Sample 2	1112	63	5.67	

This indicates the quantity of fines and impurities present in the gravel. The tests carried out show a cleanliness degree for the 5/16 gravel of 0.21% (from table 10), which, according to standard XP P18-591, is very suitable as the reference value is 5 per cent. As for the 16/25 gravel, the figure is 6.08% (from table 10); before use, we will sieve it through a 5 mm sieve and then use the oversize material, or failing that, wash it so that the material does not absorb too much water during mixing. Once this deviation has been corrected for the 16/25 gravel, we will obtain a more consistent mix.

4.7. Mix design of the concrete

The particle size curve for mix design is presented on figure 10.

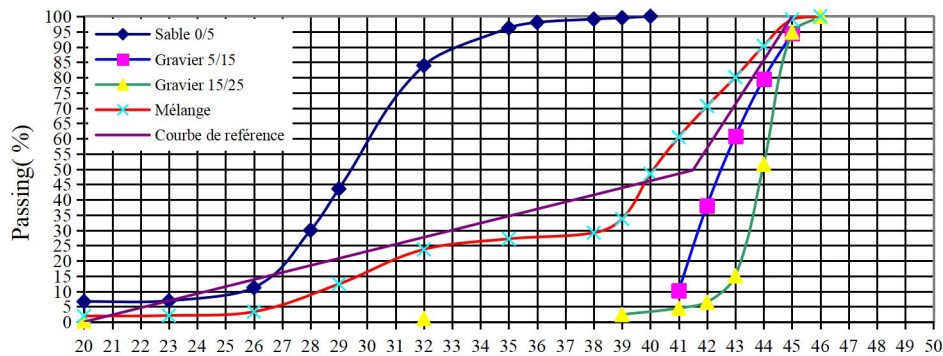


Figure 10: Mix design curve of the concrete

The particle size distribution curve for the concrete mix of figure 10 obtained from 30% of sand 0/5, 42% of gravel 5/16 and 20% of gravel 16/25 shows satisfactory continuity. The various granular fractions ensure a gradual distribution of grain sizes, minimising intergranular voids and promoting good compaction of the matrix. This distribution is suitable for the concrete mix design under consideration.

4.8. Average compressive strengths of the concrete specimens

The values of average compressive strengths of concrete specimens at 28 days and 35 days are presented in table 11.

Table 11: Compressive strengths of concrete specimens at 28 and 35 days

Average compressive strengths of concrete specimens at 28 and 35 days (MPa)			
	With Sika ViscoCrete - 2025 HE superplasticiser		
	0%	0.3%	2%
Average compressive strength of concrete specimens at 28 days (MPa)	31,2	31,6	32,725
Average compressive strength of concrete specimens at 35 days (MPa)	32,5	33,02	34,19

According to table 11, the average compressive strengths obtained increased from 31,2 MPa for 0% superplasticiser to 32,725 MPa for 2% superplasticiser at 28 days and from 32,5 MPa for 0% superplasticiser to 34,19 MPa for 2% superplasticiser at 35 days, meeting requirements for high resistant concretes. These values are higher than those obtained by Moundom *et al.* 2022 varying from 17,20 MPa, 21,41 MPa and 19,25 MPa at 28 days using of superplasticiser on concretes made with aggregates from SAFRICAS in Democratic Republic of Congo.

4.9. Water absorption of hardened concrete

The average water absorption coefficient of hardened concrete is presented in Table 12.

Table 12: Water absorption of hardened concrete

Water absorption of hardened concrete (%)			
	With Sika ViscoCrete - 2025 HE superplasticiser		
	0%	0.3%	2%
Water absorption of hardened concrete (%)	2.01	1.75	1.29

From table 12, the average water absorption coefficients on the hardened concrete decrease from 2.01 % for 0% superplasticiser to 1.29% for 2% superplasticiser. This particularly low value 1,29% reflects the excellent compactness of the cementitious matrix as well as the material's very low porosity. This performance is the result of several favourable factors, notably the quality of the aggregates used, their low water absorption, and the continuous gradation of the mix, the cement content of 400 kg /m³ and the low water-to-cement ratio adopted in the mix design. The use of a superplasticiser also improved the workability of the concrete without significantly increasing the quantity of mixing water. A water absorption of 1.29% is consistent with the result reported by AMBA (2017) of the University of Douala, which recorded a value of 3.2 per cent, indicating very low permeability of the concrete and high resistance to the penetration of water and aggressive agents; it falls into the first class with a value below 4 per cent. This characteristic is an important indicator of durability, particularly for foundation structures such as piles. In light of the generally accepted criteria for high-performance concrete, the concrete studied demonstrates an excellent ability to meet durability requirements and can be considered compliant in terms of its resistance to water penetration.

CONCLUSION

The durability of offshore structures is a major challenge in the context of port infrastructure development in Cameroon. Quay piles, which are permanently submerged in a marine environment, are particularly exposed to physico-chemical stresses that can impair their performances and reduce their lifetime. To tackle this challenge, this study focuses on the design of a low-permeability hydraulic concrete intended for this type of structures. The objective of this work is to design a durable concrete using local materials whilst limiting the penetration of aggressive agents into the cementitious matrix. The materials used are Sanaga sand 0/5, crushed gravels 5/16 and 16/25 from the Logbadjeck quarry, Dangoté cement CEM II 42.5 R, water and the Sika ViscoCrete - 2025 HE superplasticiser. The Sika ViscoCrete - 2025 HE is used for all concretes where we want great workability with a low water/cement ratio, short term high mechanical strengths, and low porosity. Its dosage varies between 0.3 and 2% by weight of cement and the values 0%, 0.3% and 2% are considered in this work. The aggregates underwent physical and mechanical characterisation through several laboratory tests (gravel cleanliness, sand equivalent, particle size analysis, specific gravity, bulk density and water absorption). The concrete mix design was carried out using the Dreux-Gorisse method, chosen for its suitability for local materials and its ability to optimise concrete compactness. Compressive and tensile strength tests were carried out on hardened concrete. The results obtained showed an average compressive strength increasing from 31,2 MPa for 0% superplasticiser to 32.725 MPa for 2% superplasticiser at 28 days and from 32,5 MPa for 0% superplasticiser to 34.19 MPa for 2% superplasticiser at 35 days. The average water absorption coefficients on the hardened concrete decreased from 2.01 % for 0% superplasticiser to 1.29% for 2% superplasticiser. The study also highlighted the importance of granular compactness and control of the water-to-cement ratio in reducing permeability and improving the durability of concrete in a marine environment or for offshore construction. The results demonstrated that it is possible to produce, using locally available materials in Cameroon, a durable hydraulic concrete suitable for the construction of permanently submerged quay piles. For further works, values of superplasticiser of 0.5, 1, and 1.5% should be investigated.

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